JC05 Rec'd PCT/PTO 28 FEB 2002

FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		ATTORNEY'S DOCKET NUMBER **220188US2PCT** U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 10/069599
INTERNATIONAL APPLICATION NO. **PCT/FR01/01813**	INTERNATIONAL FILING DATE **12 June 2001**	PRIORITY DATE CLAIMED **30 June 2000**

TITLE OF INVENTION
PUMPED LASER AND OPTIMIZED LASING MEDIUM

APPLICANT(S) FOR DO/EO/US
FEUGNET Gilles et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.
4. ☐ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☐ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☐ Certificate of Mailing by Express Mail
23. ☒ Other items or information:

PCT/IB/304/Drawings (4 sheets)/PCT/IB/308
Form PTO-1449/Notice of Priority/Cited References (3)

JC13 Rec'd PCT/PTO 28 FEB 2002

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR) 10/069599	INTERNATIONAL APPLICATION NO. PCT/FR01/01813	ATTORNEY'S DOCKET NUMBER 220188US2PCT

24. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

		CALCULATIONS	PTO USE ONLY
☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO	**$1040.00**		
☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO	**$890.00**		
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO	**$740.00**		
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)	**$710.00**		
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4)	**$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =		**$890.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).		**$0.00**	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	17 - 20 =	0	x $18.00	**$0.00**	
Independent claims	2 - 3 =	0	x $84.00	**$0.00**	
Multiple Dependent Claims **(check if applicable)**.			☒	**$280.00**	
TOTAL OF ABOVE CALCULATIONS =				**$1,170.00**	
☐ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.				**$0.00**	
SUBTOTAL =				**$1,170.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				**$0.00**	
TOTAL NATIONAL FEE =				**$1,170.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☐				**$0.00**	
TOTAL FEES ENCLOSED =				**$1,170.00**	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of **$1,170.00** to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ______ in the amount of ______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Surinder Sachar
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22850

Surinder Sachar
SIGNATURE

C. Irvin McClelland
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21,124
REGISTRATION NUMBER

Feb 28 2002
DATE

Pumped laser and optimized lasing medium

The invention relates to pumped lasers and optimized lasing media.

It can be applied more particularly to diode-pumped lasers, for example a diode-pumped laser comprising a simple coupling optical system

It can also be used as an amplifier of laser type beams.

The pumping geometry of lamp-pumped lasers is almost exclusively what is called a transverse pumping geometry, i.e. the direction of propagation of the beam in the optical cavity and the greatest dimension of the lamps are parallel. The light emitted by the lamps penetrates the lasing medium through its transverse faces.

With laser diodes, whose emission is more directional than that of a lamp, it is possible to envisage another pumping geometry known as longitudinal pumping geometry. In this case, the pump beam and the laser beam get propagated in directions close to each other, and the efficiency of the laser is promoted when these two beans get superimposed with similar sections in the lasing medium. It is also possible to encourage operation in the fundamental TEM_{00} mode of the stable cavity when the dimension of the pumped beam is close to that of the fundamental mode.

The fundamental laser beams of stable cavities have circular sections or more or less elliptical sections that do not necessarily coincide with the shape of the emissive surfaces of the laser diodes. To obtain the superimposition of the pumped laser with the beam of the laser, there are known ways of using an optical system for the focusing or reshaping of the emitted light.

For example, the making of a longitudinally pumped laser requires the use of an optical system that focuses the light emitted by one or more high-power laser diode arrays.

Figure 1 shows an exemplary laser diode array 1 comprising several elementary laser diodes positioned side by side. Each of the laser diodes has an emissive zone whose width l_b varies from a few microns to some hundreds of microns for example, and a height h_b of about one micron. The extent of the emission zone proves therefore to be highly dissymmetrical. Indeed diode arrays generally have a size of about one cm

and a divergence $\theta_{//}$ of about 10° in the plane $D_{//}$ parallel to the junction. In the plane $D_{\perp}$ perpendicular to the junction the size is in the range of one µm and the divergence $\theta\perp$ is 50°. Thus, the extent of an array is about 2000 times greater along the plane $D_{//}$ than it is along the plane $D_{\perp}$. The high value of the extent in the plane $D_{//}$ and the great dissymmetry between $D_{//}$ and $D_{\perp}$ make it difficult to design optical systems for the focusing of light emitted with the active lasing medium.

Given the present-day characteristics of high-power arrays, the light emitted may be focused on a spot with diameter of about 1 to 2 mm with efficiency values of at least 70% (the ratio between the mean power transmitted and the mean power emitted).

At output of an optical system such as this, the light is highly divergent and this is inconvenient because:

- the oscillation threshold of the laser increases with the volume in which the pump energy is deposited, and,
- a multimode operation may be induced if this volume is greater than the volume taken up by the fundamental mode of the cavity.

There are known ways to reduce these phenomena by using highly doped crystals: the volume needed to absorb the pump power diminishes as the absorption coefficient increases. This approach however has certain drawbacks, for example:

- it fosters the appearance of aberrations, strains and birefringence due to thermal causes: correcting these defects becomes difficult and the TEM_{00} mode of operation is no longer possible,
- it reduces the amount of pump energy that can be deposited without reaching the damage threshold of the material, and
- it limits the choice of the laser materials

There also exist known ways in the prior art of using non-homogeneously doped lasing media.

For example, certain lasers having a transverse pumping geometry using non-uniformly doped media in order to select the desired mode.

In other applications, the geometry of the longitudinally pumped laser arrays is such that the section of the array is very small as compared with the length using the guidance of the pump light by total reflection on the periphery of the array. However, mode selection by doping is not achieved. An exemplary embodiment is given in the references E.C.Honea and al, Optics Letters, p 1203, OSA 1998 or E.C.Honea and al, Optics Letters, p 154, OSA 1999.

The idea of the invention consists especially in using a non-homogeneously doped material as an active lasing medium, this material comprising one or more zones in which the distribution of the dopants is chosen, in particular, according to a favored mode of the laser, such as the desired transverse mode.

It relies also on the association of a simple optical focusing system that comprehensively treats the light source coming from the diode with the non-uniformly doped active lasing medium.

The invention relates to a longitudinally pumped laser comprising one or more active lasing media arranged in an optical cavity and at least one pumping means emitting at least one pumping beam toward the active lasing medium or media, means for the coupling of the pumped beam or beams with the active medium. The invention is characterized in that at least one of the active lasing media comprises one or more non-homogeneously doped zones and in that the dimension of said doped zones and/or the distribution of the dopants is chosen on the basis of the desired transverse mode of the laser cavity.

The doped zone is positioned for example substantially centrally in the active medium, its dimensions are adapted to the fundamental mode of the laser cavity or to the transverse mode and the non-doped peripheral zone has dimensions adapted to the coupling means.

The section s_d of the input face of the doped zone that receives the pump beam is for example smaller than or equal to the section s_m of the fundamental mode of the cavity.

The section s_d of the input face of the doped zone that receives the pump beam may be at least greater than the section s_m of the fundamental mode of the cavity, the laser cavity comprising a selection device.

According to another embodiment, the active lasing medium comprises a non-doped central zone surrounded by a doped peripheral zone.

The doped zone has, for example, a parallelepiped or circular or elliptical shape.

The one or more pumping means may comprise one or more diode arrays and the coupling means may consist of a light concentrator adapted to receiving all the light emitted by the diode arrays.

The coupling means comprise for example at least one of the devices chosen from the following list: a refractive focusing system or a diffractive focusing system, or a system working by reflection or a system for reshaping the extent of a beam.

The distribution of the dopants in the active medium is made for example according to a gradient.

The dopants are chosen for example from among one or more of the ions of the following list: : (Nd^{3+}, Yb^{3+}, Er^{3+}, Ho^{3+}, Th^{3+},....).

The face of the active medium facing the coupling means is treated so as to be anti-reflective at the pumping wavelength and reflective at the laser wavelength and the opposite face of the active medium is treated so as to be anti-reflective at the laser wavelength.

The invention also relates to a method for the manufacture of an active medium used in lasers. It is characterized in that it comprises at least one step for the making of one or more pieces of a doped matrix and a non-doped matrix so as to obtain an active medium comprising one or more zones or volumes having a dimension and/or a distribution of the dopants chosen to obtain a transverse mode of the laser cavity.

The manufacturing step may be a step of joining by gluing, molecular adhesion or again diffusion bonding.

According to another mode of manufacture, the manufacturing step is a step for preforming a step-index fiber or for preforming a fiber with a graded index of dopants.

Use of the laser having one of the characteristics mentioned here above to amplify one or more laser type beams.

The laser according to the invention has in particular the following advantages:

- the depositing of the pump light in a volume compatible with operation in the fundamental mode (TEM_{00}) and the favoring of this mode over the higher orders ,
- the making of a simple focusing system that is independent of the structure of the laser array (pumping means) and is a potentially low-cost system;
- the overcoming of the problem of the divergence of the incident light on the lasing medium without having to use highly doped materials,
- the depositing of the pump energy in a large volume as compared with prior art lasers and the reduction, in this way, of thermally caused optical aberrations, the energy being distributed in a greater volume,
- not crossing the damage (or impairment) threshold of the laser material despite high pump power values.

Other advantages and characteristics of the invention shall appear more clearly from the following description given by way of a non-restrictive example, with reference to the appended figures, of which:

- Figure 1 shows an exemplary prior art laser diode,

- Figure 2 is a drawing of an exemplary architecture of the laser according to the invention,

- Figures 3a and 3b show the propagation of a light ray in the non-homogeneously doped active medium,

- Figure 4 shows a variant of a pump laser diode,

- Figure 5 illustrates two exemplary coupling optical systems known to those skilled in the art, and

- Figures 6 and 7 are two exemplary drawings using the laser according to the invention as an amplifier.

To provide for a clearer understanding of the principle of operation of the laser according to the invention, the following description, given by way of an illustration that in no way restricts the scope of the invention, relates to a diode-pumped laser associated by means of a simple coupling optical system with a non-uniformly doped active lasing medium, in particular to favor the transverse TEM_{00} mode of the laser cavity. .

Figure 2 shows an exemplary architecture of a laser module according to the invention. This module consists of a non-homogeneously doped active lasing medium 3 that favors a particular laser mode such as the transverse TEM_{00} mode, a pump laser diode 4, means 5 for coupling the pump beam coming from the pump laser diode 4 to the active lasing medium 3. The laser cavity is closed by a mirror 6.

The mirror 6 is positioned for example in the optical axis of the laser, perpendicularly to the laser beam. It has transmission characteristics suited to optimizing the working of the laser.

Pump laser diode

The pump laser diode 4 may be a unitary laser diode, or an assembly of laser diodes (linear arrays, stack of linear arrays, surface emission plates etc) as described for example in figure 1, or again any assembly of diodes or unitary diodes. The beam emitted by such a structure is for example reshaped before it is transmitted to the active lasing medium.

The laser diode may also take the form of several linear arrays positioned in such a way that the emission takes place in all three dimensions. An example of such a structure is given in figure 4. Such a structure may be used with or without a coupling optical system.

Coupling means

The coupling means 5 are adapted to the type of pump laser diode used. For longitudinal type pumping, it is possible for example to use a light concentrator as described in one of the following references:

[1] " High efficiency TEM_{00} Nd :YVO_4 laser longitudinally pumped by a high power laser diode array ", SPIE Proceedings,

[2] G.Feugnet, C.Bussac, M.Schwartz, C.Larat and J.P Pocholle " Nonimaging optics III : Maximum Efficiency Light Transfer ", in Opt. Lett. 20, pp 157-159, 1995.

The dimension of the concentrator 5 corresponding to the width of the laser rod in the parallel plane $D_{//}$ is equal, for example, to 1.5 mm. The thickness e_c of the light concentrator is substantially constant and equal to 1.5 mm. The output face of the concentrator has a square section s_c substantially equal to $(1.5*1.5)\ mm^2$.

Active lasing medium

The active lasing medium 3 is formed, for example, by a composite rod comprising a doped central region 8 having a parallelepiped shape with a square section s_d, for example, surrounded by a non-doped peripheral region 9, namely a zone having practically no dopant and even no dopant at all.

The dopant used for the active medium is chosen, for example, from among one or more of the ions of the following list : (Nd^{3+}, Yb^{3+}, Er^{3+}, Ho^{3+}, Th^{3+},....).

The active lasing medium is, for example, a solid medium that has several laser transitions (YAG :Nd, YVO_4 :Nd, sapphire :Ti, etc) and is known to those skilled in the art.

The doped zone 8 has a length L_d substantially equal to the length L_l of the active lasing medium, a section s_d, and a volume V_d corresponding to s_d*L_d. The pump light is deposited or absorbed in this volume V_d, for example according to the scheme described in figures 3a and 3b.

The doped zone 8 has dimensions adapted to the fundamental mode of the laser cavity for example. These dimensions may also be fixed so as to promote the appearance of other transverse modes. Its length is for example chosen as a function of the quantity of light to be deposited and of the absorption.

<u>Determining the dimensions of the doped zone</u>

One way to determine the geometry and the dimensions of the non-uniformly doped zone and/or the distribution of the dopants comprises, for example, the following steps:

- From the characteristics of the emissive source (the laser diode) such as its dimensions, its divergence values etc., an optical focusing system is designed. The optical focusing system is determined, for example, so that its transmission is as efficient as possible, according to criteria known to those skilled in the art. Typically, the light is focused on a spot whose section s_l is some square millimeters,
- The section of the non-uniformly doped rod is adapted to the dimensions of the light spot.

- For example, the section of the rod may be substantially square, equal to or slightly greater than that of the output face of the concentrator,
- For a cylindrical rod, the diameter is substantially equal to or slightly greater than the diagonal of the output face of the concentrator,
- The dimensions may also be chosen to take account of the positioning tolerances of the rod with respect to the concentrator and the quality of the edges of the rod.
- In the case of a focusing that uses a lens, the section of the rod is adapted so that the transmission T through a fictitious aperture with identical dimensions is in the range of 100%

with $T=\iint_{\text{aperture section}} I(x,y)dxdy \Big/ \iint_{\infty} I(x,y)dxdy$

where I(x,y) is the distribution of the intensity at the focusing point of the light,

- The ratio r between the dimensions of the doped zone and those of the non-doped zone is defined in taking account of the characteristics of the pump radiation taken after the optical coupling system 5, the spectroscopic characteristics of the laser material and the technological constraints related to the making of the non-uniformly doped rod. The spectroscopic characteristics of the laser material may be recorded during preliminary tests using methods known to those skilled in the art.
  - The process of determining the ratio r takes place, for example, iteratively, and comprises, for example, the following steps :
    - during a first step a), fixing the value of the ratio r at a value r_0,
    - computing (second step b)) the pump energy distribution in the rod and the associated thermal effects from this value in implementing a ray tracing program and a thermal computation program,
    - during a third step c), designing a laser cavity whose TEM_{00} mode is close to the dimensions of the doped zone, for example by means of a laser cavity computation program taking account of the thermal effects,

- If the TEM_{00} mode determined is different or far too remote, changing the initially chosen ratio and restarting the steps a) to c). The value of the length of the laser cavity may indeed be limited for reasons of space requirement.

The different computation methods implemented in the steps described here above are known to those skilled in the art.

When determining the value of the ratio r, it is necessary to take account of the following constraints:

- the influence of its value on the rod length needed to absorb the energy, it being known that the length may be limited for reasons of technology,
- the influence of its value on the energy absorbed per unit of length which must remain much below the optical damage threshold.

To obtain efficient discrimination between the fundamental mode of the cavity and the higher-order modes, thus favoring the TEM_{00} operation, the dimensions of the doped zone are chosen as a function of the dimensions of the fundamental mode of the laser cavity.

Thus, the section s_d of the doped zone is preferably smaller than or equal to the section s_m of the fundamental mode of the cavity. It may also be slightly greater than or greater than the section of the fundamental mode associated with another selection device.

The section s_m of the fundamental mode corresponds, for example, to the section of the laser beam taken at about 13.6 % of the maximum.

The steps described with reference to a square geometry may also be applied in the case of a cylindrical geometry, in assuming, in this case, the cylindrical section of the doped zone.

The interface between the doped zone 8 and the peripheral zone 9 will be made so as to minimize the losses like to hamper or impair the operation of the laser according to techniques known to those skilled in the art.

The dimensions of the peripheral zone 9 are chosen, for example, as a function of the performance characteristics of the focusing optical system, for example the focusing spot, the divergence of the radiation after the focusing point. The section S_{nd} and S_d is substantially equal to the section S_c of the face of the concentrator positioned before it. The length L_{nd}

of the non-doped zone corresponds, for example, to the length of the material or active medium forming the laser. It may correspond to the length L_d of the doped zone.

Without departing from the framework of the invention, the doping may also be obtained in the form of a gradient of dopants distributed non-homogeneously in the material forming the active medium. The gradient, the distribution of the dopants as well as their nature will be determined according to the mode of operation chosen for the laser.

According to another alternative embodiment, the rod comprises a totally non-doped section at least at one of its ends. With this technique, it is possible to reduce the deformations at the ends of a rod. The contact between the non-doped sections and the non-homogeneously doped sections may be obtained by a diffusion bonding technique known to those skilled in the art.

The two external face 10, 11 of the composite rod are polished so as to guide the pump light by total or practically total reflection.

The face 10 of the composite rod that is facing the concentrator 5 is provided with a treatment that makes it anti-reflective at the pumping wavelength and totally reflective at the laser wavelength.

The opposite face 11 of the rod is treated to be anti-reflective at the laser wavelength. This face may be angle-polished so that the beam has an angle of incidence with a value close to the Brewster's value. During the mounting of the laser rod, the necessary precautions will be taken to prevent a part of the beam from getting propagated in another attached medium.

Figures 3a and 3b give a schematic view of an exemplary path of the pump light in the active lasing medium comprising a parallelepiped shaped central doped zone as shown in figure 2. During its propagation in the laser rod, the laser beam does not necessarily cross the non-doped zone at each reflection. The power of the pump is deposited solely in the central doped zone, thus favoring the TEM_{00} operation. Furthermore, a structure of this kind overcomes the divergence of the pump light incident on the composite medium.

Thus, on the paths 12 shown in dotted lines, there is no absorption of light whereas on the paths 13 of the light rays shown in solid lines, the light ray is absorbed. The pump light is guided by reflection on the

lateral faces of the lasing medium, by total internal reflection or by reflection on a dielectric treatment, and thus makes a zigzag path in the composite rod, in depositing the energy solely in the doped zone 8. After a sufficient number of reflections, all the power of the pump will be absorbed.

The geometry (shape and dimensions) of the non-doped zone is adapted to optimizing the number of beams that cross it while at the same time providing for guidance by total reflection.

In comparison with the highly doped structures mentioned here above, the pump power is distributed in a volume greater than that usually offered by prior art lasers. This especially reduces the aberrations, constraints and birefringence arising out of thermal causes.

According to another alternative embodiment, the active medium comprises the non-doped central zone and a dope peripheral zone. In this case, the light path will deposit energy no longer centrally but on the periphery of the composite rod, thus favoring the higher-order modes. This arrangement favors the mode usually known as the ring mode.

According to another variant, known for example in the field of what are called "double clad" fibers, described for example in the US 4,815,079, the doped zone is off-centered with respect to the zone that guides the pump or again the guiding zone has a particular shape, for example a D shape.

With these embodiments, which consist in breaking the symmetry of the optimized medium, the number of the light phase (or propagation modes for the fibers) that never penetrate the doped zone and are not absorbed can be reduced. The absorption is thus augmented.

<u>Method of manufacture of a composite rod forming the emissive medium</u>

Several methods of manufacture may be implemented to make the active lasing medium.

One method of making a non-homogeneously doped composite rod comprises, for example, steps for assembling the doped or non-doped discrete pieces of a matrix which will have been polished before assembly.

The matrix is chosen for example from the following list : YAG, YLF, YVO_4, GdCOB, glass.

The different pieces are assembled according to the desired doping geometry, for example :

- by gluing, with a glue having an appropriate index, such as an optical glue known to those skilled in the art,
- by molecular bonding,
- by diffusion bonding or soldering by interdiffusion at the interfaces between the pieces. This technique especially offers higher resistance to impacts and ensures low losses at the interfaces.

Another procedure would lie in the use of techniques used in the field of optical fibers and known to those skilled in the art. The advantage of these techniques is that they involve carrying out a preform with a doped part and a non-doped part of a step-index fiber or again a preform with a gradual transition between the doped zone and the non-doped such as the preforming of a graded-index fiber. The dopants are distributed in the form of a gradient within the doped zone.

This preform may be drawn to make its diameter compatible with the dimensions needed for this application. The matrix is for example made of glass with different compositions such silicate, phosphate, fluoride or any other material to which the drawing technique is adapted.

A technique of this kind can be used especially to make circular-sectioned dope zones particularly well suited to the section of the fundamental modes of the cavity.

In the different applications of the laser assembly comprising a diode-pumped laser with a lasing medium according to the invention, different focusing means may be used

To carry out the focusing function, two approaches may be singled out :

- A first approach consists in taking account of the discontinuous nature of the light source and in imaging each of the diodes of the array. Systems based on optical fiber beams, using optical injection into one or more optical fibers, refractive optical devices such as lenses, cylindrical lenses, diffractive optical devices such as holographic lenses, micro-lenses, reflection systems such as, for example, micro-mirrors, or again any combination of these systems may be used. They provide for an efficient focusing of light because the non-emissive zones

are not taken into account. They are used more particularly for arrays having a small number of emitters.

- In a second approach, for example, the array is considered in its entirety without taking account of the discontinuous nature of the source. Systems based on macroscopic lenses or concentrators correspond, for example, to this approach. These systems have the advantage of being relatively simple to make. They can also be used whatever the number of emitters, and the light source is interchangeable.

It is also possible to use systems for the redistribution of the extent or for reshaping the geometrical extent of the beam, for example as shown in figure 5.

Without departing from the framework of the invention, the laser according to the invention can also be used as an amplifier of a laser beam.

Figure 6 gives a schematic view of an exemplary embodiment for the use of the structure comprising a non-uniformly doped rod as described in figure 2 to amplify a laser beam coming from a laser source.

The incident laser beam 20 penetrates the amplifier structure 21 at an angle different from zero and emerges therefrom for example with a direction substantially parallel to the incident direction in the form of an amplified laser beam 22.

The angle of incidence must be small so that the beam crosses the totality or at least the greater part of the doped zone. The section of the beam may be slightly smaller than the section of the doped zone.

The dimensions of the doped and non-doped zones are chosen in order to augment the energy of the incident beam while preserving the laser mode, for example, the TEM_{00} mode.

With such a use it is advantageously possible to increase the energy of the beam while preserving the TEM_{00} operating mode.

The amplified laser beam may be a laser beam coming from a femtosecond laser.

The laser structure according to the invention can also be used as a regenerative amplifier, an exemplary embodiment of which is given in figure 7.

In this exemplary embodiment, a laser beam F_e to be amplified reaches a polarizer 30 adapted to transmitting the totality (100%) of this beam or at least the greater part of it to a device such as a Pockels cell 31 that acts especially as a phase delay plate and is known to those skilled in the art. At the entry to the Pockels cell, the beam F_e possesses, for example, a linear polarization. It comes out of this cell with a circular polarization and is then transmitted to the block 32 comprising the active elements described in 2, especially the non-homogeneously doped laser medium, the mirror 6 being replaced by a laser cavity mirror 33 positioned after the polarizer. F_1 gets reflected on the face 10 of the non-uniformly doped rod and emerges by the face 11. It then passes through the Pockels cell 32 from where it emerges with a polarization substantially perpendicular to its initial polarization (that of the beam F_e). It is thus transmitted to the laser cavity mirror 33 on which it will get reflected. The beam F_1 is then trapped in the structure comprising the block 32 and the mirror 33, the Pockels cell enabling this beam to enter and exit. It thus makes several return trips during which it acquires energy, and is therefore amplified. The value of the gain G obtained depends especially on the number of return trips and on the structure of the non-homogeneously doped rod.

When the beam F_1 has acquired the desired gain, the Pockels cell is used to extract it, the output beam F_s being equal to $G*F_e$.

Since the working of a Pockels cell is known to those skilled in the art, it has not been described in detail.

In general when the device is used as an amplifier of a laser beam, it comprises at least the following elements : a light source whose function especially is to excite a lasing medium, a device for coupling the light beam coming from the source to the laser medium. The lasing medium comprises at least one doped zone and one non-doped zone, having one of the characteristics stated with reference to figure 2 so as to augment the energy of one laser beam to be amplified.

CLAIMS:

1. Longitudinally pumped laser comprising one or more active lasing media arranged in an optical cavity and at least one pumping means (4) emitting at least one pumping beam toward the active lasing medium or media (3), means (5) for the coupling of the pumped beam or beams with the active medium, characterized in that at least one of the active lasing media comprises one or more non-homogeneously doped zones (8) and in that the dimension of said doped zones (8) and/or the distribution of the dopants is chosen on the basis of the desired transverse mode of the laser cavity.

2. Laser according to claim 1 characterized in that the doped zone (8) is positioned substantially centrally in the active medium (3), its dimensions are adapted to the fundamental mode of the laser cavity or to the transverse mode and in that the non-doped peripheral zone has dimensions adapted to the coupling means (5).

3. Laser according to one of the claims 1 or 2, characterized in that the section s_d of the input face of the doped zone that receives the pump beam is smaller than or equal to the section s_m of the fundamental mode of the cavity.

4. Laser according to one of the claims 1 or 2, characterized in that the section s_d of the input face of the doped zone that receives the pump beam is at least greater than the section s_m of the fundamental mode of the cavity, the laser cavity comprising a selection device.

5. Laser according to claim 1, characterized in that the active medium (3) comprises a non-doped central zone surrounded by a doped peripheral zone.

6. Laser according to one of the above claims, characterized in that the doped zone has a parallelepiped or circular or elliptical shape.

7. Laser according to one of the claims 1 to 6, characterized in that said one or more pumping means (4) comprise one or more diode arrays and the coupling means (5) consist of a light concentrator adapted to receiving all the light emitted by the diode arrays.

8. Laser according to one of the claims 1 to 6, characterized in that said coupling means comprise for example at least one of the devices chosen from the following list: a refractive focusing system or a diffractive focusing

system, or a system working by reflection or a system for reshaping the extent of a beam.

9. Laser according to claim 1, characterized in that the distribution of the dopants in the active medium is made according to a gradient.

10. Laser according to one of the above claims, characterized in that the dopants are chosen from among one or more of the ions of the following list: : (Nd^{3+}, Yb^{3+}, Er^{3+}, Ho^{3+}, Th^{3+},....).

11. Laser according to one of the above claims, characterized in that the face of the active medium facing the coupling means is treated so as to be anti-reflective at the pumping wavelength and reflective at the laser wavelength, and the opposite face of the active medium is treated so as to be anti-reflective at the laser wavelength.

12. Method for the manufacture of an active medium used in lasers, characterized in that it comprises at least one step for the making of one or more pieces of a doped matrix and a non-doped matrix so as to obtain an active medium comprising one or more zones or volumes having a dimension and/or a distribution of the dopants chosen to obtain a transverse mode of the laser cavity.

13. Method of manufacture according to claim 12 characterized in that the manufacturing step is a step of joining by gluing, molecular adhesion or diffusion bonding.

14. Method of manufacture according to claim 12, characterized in that the manufacturing step is a step for preforming a step-index fiber or for preforming a fiber with a graded index of dopants.

15. Use of the laser according to one of the claims 1 to 11 to amplify one or more laser beams.

ABSTRACT

Pumped laser and optimized lasing medium

Longitudinally pumped laser comprising one or more active lasing media arranged in an optical cavity and at least one pumping means (4) emitting at least one pumping beam toward the active lasing medium or media (3), means (5) for the coupling of the pumped beam or beams with the active medium, characterized in that at least one of the active lasing media comprises one or more non-homogeneously doped zones (8) and in that the dimension of said doped zones (8) and/or the distribution of the dopants is chosen on the basis of the desired transverse mode of the laser cavity..

Use of the laser as an amplifier

Figure 2 to be published.

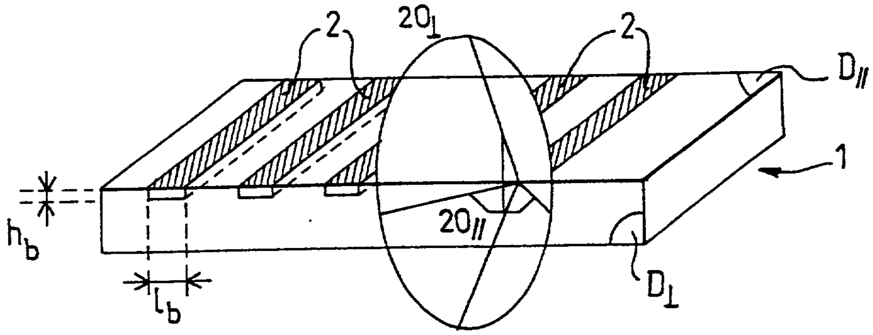


FIG.1

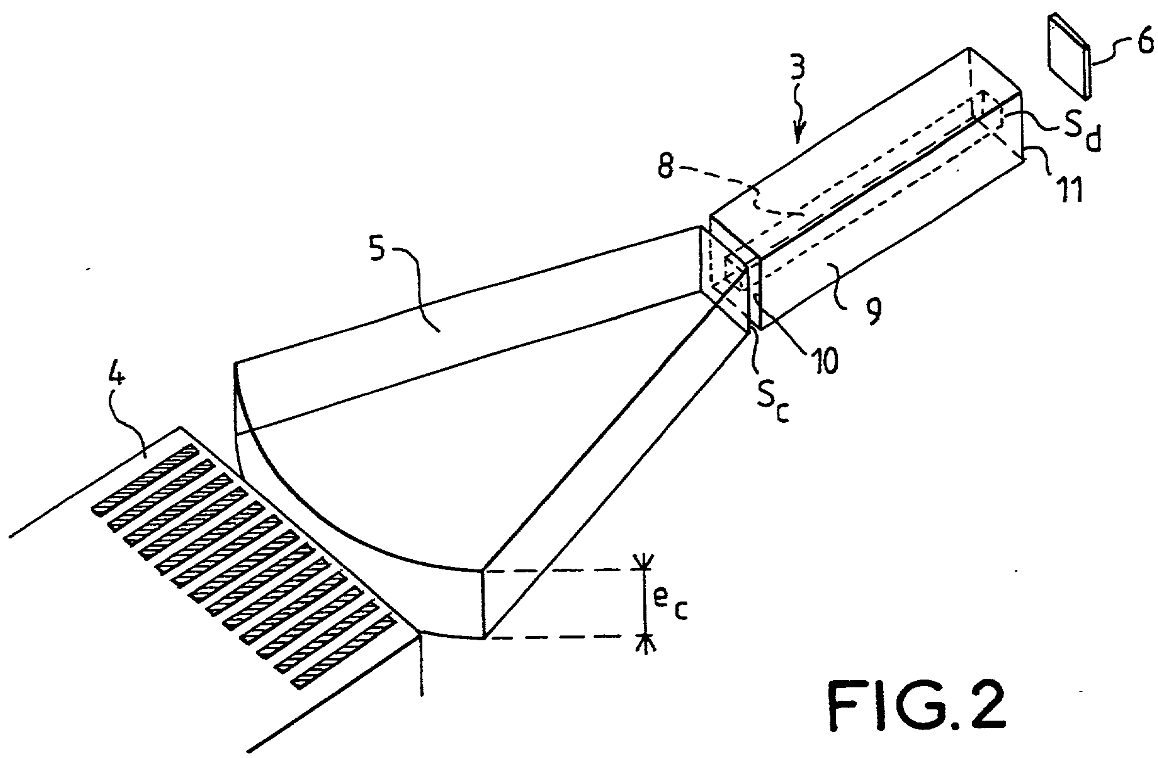


FIG.2

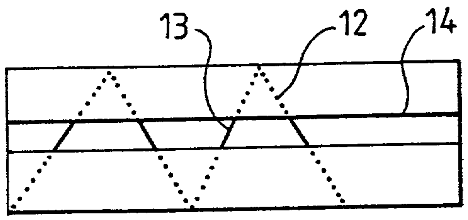


FIG.3a

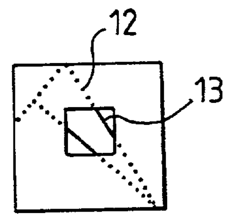


FIG.3b

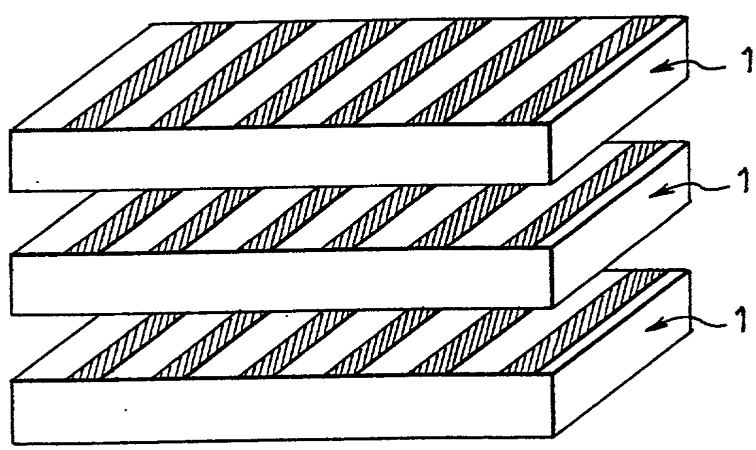
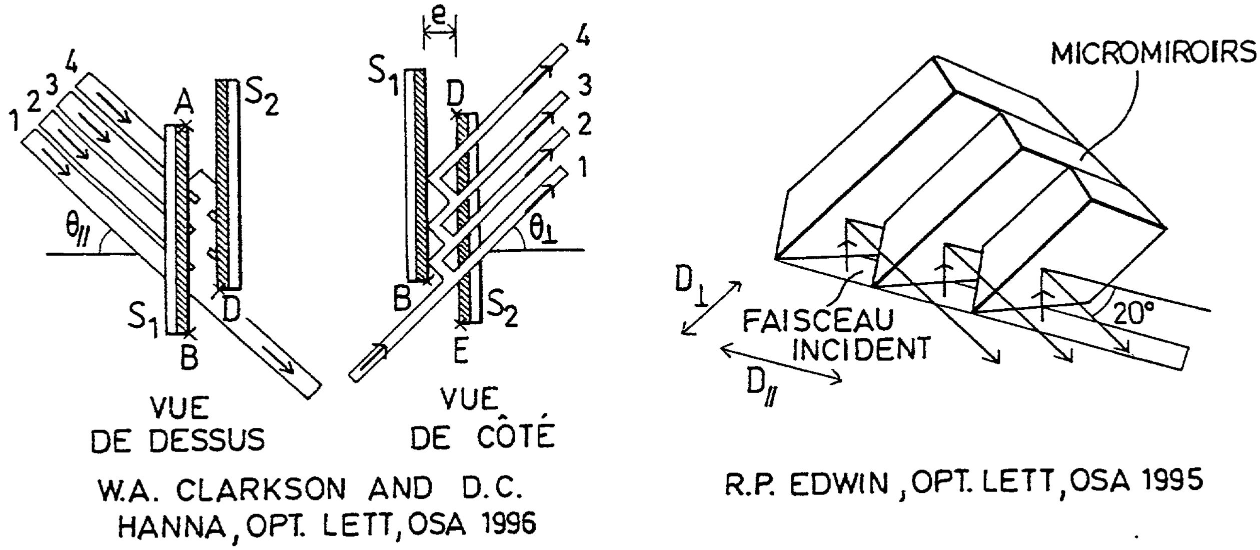


FIG.4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W.A. CLARKSON AND D.C.
HANNA, OPT. LETT, OSA 1996
MICROMIROIRS
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FAISCEAU
INCIDENT
20°
$D_{//}$
R.P. EDWIN, OPT. LETT, OSA 1995

FIG. 5

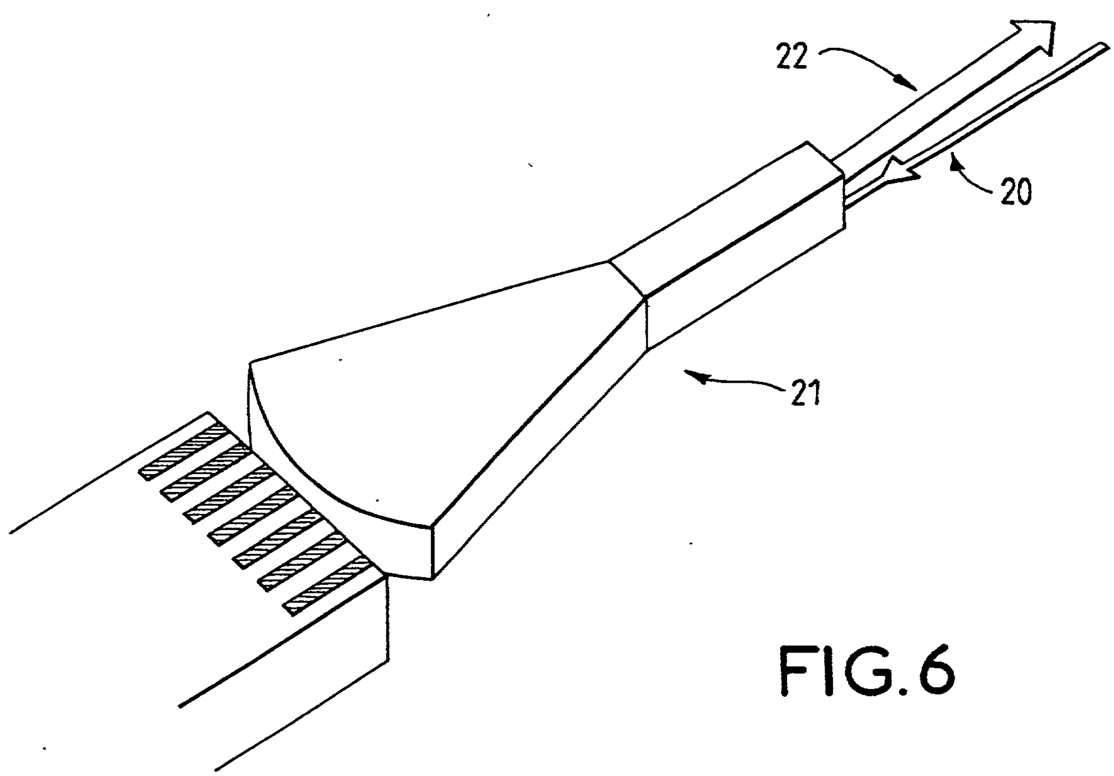
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FIG.6

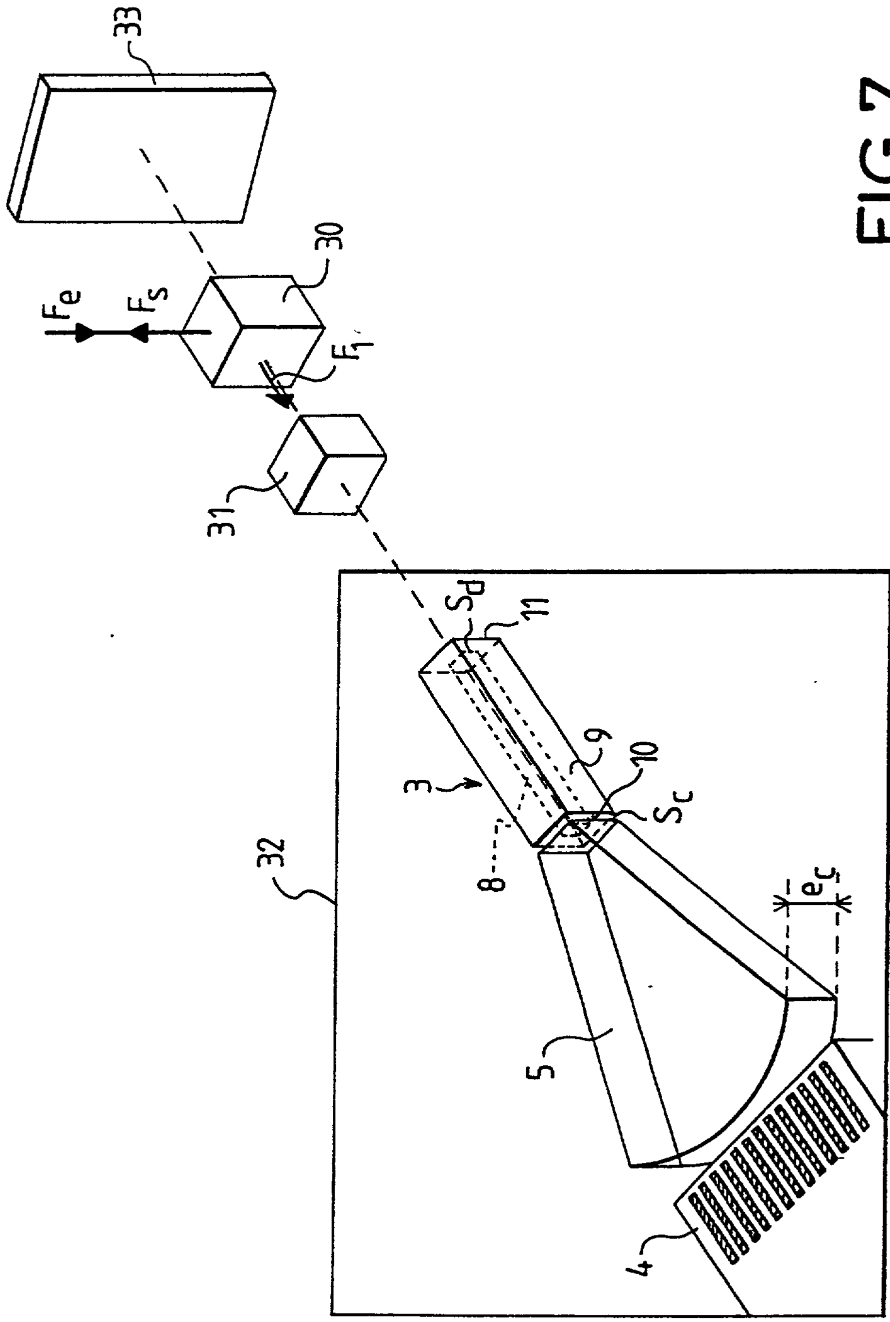

FIG.7

Declaration and Power of Attorney for Patent Application
Déclaration et Pouvoirs pour Demande de Brevet
French Language Declaration

En tant l'inventeur nommé ci-après, je déclare par le présent acte que:

Mon domicile, mon adresse postale et ma nationalité sont ceux figurant ci-dessous à côté de mon nom.

Je crois être le premier inventeur original et unique (si un seul nom est mentionné ci-dessous), ou l'un des premiers co-inventeurs originaux (si plusieurs noms sont mentionnés ci-dessous) de l'objet revendiqué, pour lequel une demande de brevet a été déposée concernant l'invention intitulée

et dont la description est fournie ci-joint

☐ ci-joint

☐ a été déposée le ______________

sous le numéro de demande des Etats-Unis ou le numéro de demande international PCT

______________ et modifiée le

______________ (le cas échéant).

Je déclare par le présent acte avoir passé en revue et compris le contenu de la description ci-dessus, revendications comprises, telles que modifiées par toute modification dont il aura été fait référence ci-dessus.

Je reconnais devoir divulguer toute information pertinente à la brevetabilité, comme défini dans le Titre 37, § 1.56 du Code fédéral des réglementations.

As a below named inventor, I hereby declare that:

My residence, mailing address and citizenship are as stated next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled.

PUMPED LASER AND OPTIMIZED LASING MEDIUM

the specification of which

☐ is attached hereto.

☒ was filed on **June 12, 2001**

as United States Application Number or PCT International Application Number

PCT/FR01/01813 and was amended on

______________ (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

French Language Declaration

Je revendique par le présent acte avoir la priorité étrangère, en vertu du Titre 35, § 119(a)-(d) ou § 365(b) du Code des Etats-Unis, sur toute demande étrangère de brevet ou certificat d'inventeur ou, en vertu du Titre 35, § 365(a) du même Code, sur toute demande internationale PCT désignant au moins un pays autre que les Etats-Unis et figurant ci-dessous et, en cochant la case, j'ai aussi indiqué ci-dessous toute demande étrangère de brevet, tout certificat d'inventeur ou toute demande internationale PCT ayant une date de dépôt précédant celle de la demande à propos de laquelle une priorité est revendiquée.

I hereby claim foreign priority under Title 35, United States Code, § 119 (a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)
Demande(s) de brevet anterieure(s) dans un autre pays.

(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Anné de dépôt)	Priority Claimed Droit de priorité Revendiqué	
00 08519	**FRANCE**	**30 JUNE 2000**	☒ Yes Oui	☐ No Non
			☐ Yes Oui	☐ No Non

Je revendique par le présent acte tout bénéfice, en vertu du Titre 35, § 119(e) du Code des Etats-Unis, de toute demande de brevet provisoire effectuée aux Etats-Unis et figurant ci-dessous.

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below.

(Application No.) (Nº de demande)	(Filing Date) (Date de dépôt)	(Application No.) (Nº de demande)	(Filing Date) (Date de dépôt)

Je revendique par le présent acte tout bénéfice, en vertu du Titre 35, § 120 du Code des Etats-Unis, de toute demande de brevet effectuée aux Etats-Unis, ou en vertu du Titre 35, § 365(c) du même Code, de toute demande internationale PCT désignant les Etats-Unis et figurant ci-dessous et, dans la mesure où l'objet de chacune des revendications de cette demande de brevet n'est pas divulgué dans la demande antérieure américaine ou internationale PCT, en vertu des dispositions du premier paragraphe du Titre 35, § 112 du Code des Etats-Unis, je reconnais devoir divulguer toute information pertinente à la brevetabilité, comme défini dans le Titre 37, § 1.56 du Code fédéral des réglementations, dont j'ai pu disposer entre la date de dépôt de la demande antérieure et la date de dépôt de la demande nationale ou internationale PCT de la présente demande:

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

(Application No.) (Nº de demande)	(Filing Date) (Date de dépôt)	(Status: Patented, Pending, Abandoned) (Statut : breveté, en cours d'examen, abandonné)
PCT/FR01/01813	**June 12, 2001**	

Je déclare par le présent acte que toute déclaration ci-incluse est, à ma connaissance, véridique et que toute déclaration formulée à partir de renseignements ou de suppositions est tenue pour véridique; et de plus, que toutes ces déclarations ont été formulées en sachant que toute fausse déclaration volontaire ou son équivalent est passible d'une amende ou d' une incarcération, ou des deux, en vertu de la § 1001 du Titre 18 du Code des Etats-Unis, et que de telles déclarations volontairement fausses risquent de compromettre la validité de la demande de brevet ou du brevet délivré à partir de celle-ci.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

French Language Declaration

POUVOIRS En tant que l'inventeur cité, je désigne par la présente l'(les) avocat(s) et/ou agent(s) suivant(s) pour qu'ils poursuive(nt) la procédure de cette demande de brevet et traite(nt) toute affaire s'y rapportant avec l'Office des brevets et des marquees *(mentionner le nom et le numéro d'enregistrement)*

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

022850

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Send Correspondence to:

022850

Adresser tout appel téléphonique à· *(nom et numéro de téléphone)*

Direct Telephone calls to *(name and telephone number)*

(703) 413-3000

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	91120 PALAISEAU France

(Fournier les mêmes renseignements et la signature de tout co-inventeur supplémentaire)

(Supply similar information and signature for third and subsequent joint inventors.)

French Language Declaration

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Signature de l'inventeur Date	Third Inventor's signature Date Christian Larat
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Nationalité	Citizenship French
Adresse Postale	Post Office Address 32 Rue Dauphine
	75006 PARIS France

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Signature de l'inventeur Date	Fourth Inventor's signature Date Jean. Paul Pocholle
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Nationalité	Citizenship French
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Signature de l'inventeur Date	Fifth Inventor's signature Date Didier Rolly
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Nationalité	Citizenship French
Adresse Postale	Post Office Address 10 Rue de L'Orme
	91460 MARCOUSSIS France

Nom complet du sixième co-inventeur, le cas echeant	Full name of sixth joint inventor, if any
Signature de l'inventeur Date	Sixth Inventor's signature Date
Domicile	Residence
Nationalité	Citizenship
Adresse Postale	Post Office Address

(Fournir les mêmes renseignements et la signature de tout co-inventeur supplémentaire.)

(Supply similar information and signature for third and subsequent joint inventors.)